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MULTI-ECHELON MODELS

OPERATIONS ANALYSIS DEPARTMENT

NAVY FLEET MATERIAL SUPPORT OFFICE

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OVERVIEW OF MULTI-ECHELON MODELS

REPORT 160

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ABSTRACT

The Navy currently uses inventory models which determine the optimal inventory policy for each activity or echelon of supply independently of the other supply activities. In addition, the Navy uses supply effectiveness measures which are requisition oriented rather than readiness oriented. Many inventory models, known as multi-echelon models, have been developed which feature both a readiness performance measure and multi-echelon supply modeling. The multi-echelon models which have been proposed for use or are currently being used by the military services have at least one of three purposes: (1) to tie budget dollars to readiness, (2) to determine the inventory levels required at each echelon of supply given a readiness objective, or (3) to predict readiness given the inventory levels at each echelon of supply. Therefore, the model which is "best" for the Navy will depend on the Navy's intended use of the model. This study examines and contrasts the characteristics of the multi-echelon models currently used or proposed for use in the military services, in order to choose models which may fit the Navy's needs.

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EXECUTIVE SUMMARY

1. Background. The Navy currently uses inventory models which determine the optimal inventory policy for each activity or echelon of supply independently of the other activities. Multi-echelon inventory models have been developed to model entire supply systems rather than the individual activities or echelons which make up the supply network. In addition, the Navy uses supply effectiveness measures which are requisition oriented rather than readiness oriented. Congress is now requiring the military services to project the effect of requested appropriations on material readiness requirements. Therefore, most multi-echelon models have been developed to feature both a readiness performance measure and the multi-echelon supply system modeling.

A plethora of multi-echelon models have been proposed for use or are currently being used by the military services for at least one of three purposes: (1) to tie budget dollars to readiness, (2) to determine the inventory levels at each echelon of supply given a readiness objective, or (3) to predict readiness given the inventory levels (however determined) at each echelon of supply.

2. Objective. To examine and contrast the characteristics of the multi-echelon models used or proposed for use in the military services, based on each model's available documentation, in order to choose models which may fit the Navy's needs.

3. Approach. Sufficient documentation was obtained to analyze 17 multi-echelon models. A matrix was developed to highlight and contrast the characteristics of these multi-echelon models. In addition to the matrix, abstracts were developed to discuss significant characteristics of the models which could not be put in the matrix and to identify characteristics which distinguish the models

from each other.

4. Findings. As discussed in the background, multi-echelon models have been developed for the military services for at least one of three purposes: (1) to tie budget dollars to readiness, (2) to determine requirements, or (3) to predict readiness given the inventory levels at each echelon of supply. Therefore, the model which is "best" for the Navy depends on how the Navy intends to use the model.

The Availability Centered Inventory Model (ACIM) was developed for the Navy for requirements determination. Based on the "documentation" analysis performed in this study, there is no reason to prefer any other requirements determination model over ACIM. However, none of the models examined in this study were exercised with data. A more in-depth analysis which concentrated on only a few of the requirements determination models (such as the Selected Essential-Item Stockage for Availability Method (SESAME), Multi-Item Multi-Echelon (MIME) and Aircraft Availability Model (AAM) in addition to the ACIM model) and tested these models with live data would be valuable. For evaluation of inventory levels, the Multi-Echelon Technique for Evaluating Operational Readiness (METEOR) and Aviation Afloat and Ashore Allowance Analyzer (5A) models, which were designed based on the Navy's inventory system, represent that system better than any of the other evaluation models. The Assessment of the Wholesale and Retail System (AWARES), CAPLOG and 5A synthesizer models should be investigated in more depth to determine if they can be used by the Navy for tying budget dollars to readiness.

5. Recommendations. FMSO recommends that the CAPLOG, AWARES and 5A synthesizer models be further analyzed for use in giving "quick and dirty" answers to tying budget dollars to readiness questions. FMSO also recommends that the ACIM, AAM,

MIME and SESAME models be further analyzed for use in requirements determination and that the METEOR and 5A models be further analyzed for use in evaluating inventory levels.

It is recommended that the additional studies be performed in the following sequence:

- Budget dollars to readiness models.
- Evaluating inventory levels models.
- Requirements determination models.

I. INTRODUCTION

The Navy currently uses inventory models which determine the optimal inventory policy for each activity or echelon of supply, within the Navy's hierarchical supply network, independently of any of the other supply activities. Optimizing at each supply echelon or activity of an organization, however, will rarely result in an optimal strategy for the whole supply system. Inventory models have been developed which model entire supply systems rather than the individual activities or echelons which make up the supply network. These inventory models are known as multi-echelon inventory models.

Historically, the Navy has used supply effectiveness measures which are requisition oriented (for example, percent of requisitions satisfied) rather than readiness oriented (for example, percent of time an equipment is operational). However, in 1977 Congress passed Public Law 95-79 which, in Section 812, requires the Department of Defense to submit an annual report to the Congressional Armed Services Committee on material readiness requirements. Additionally, the FY78 Defense Authorization Act stipulated, "The budget for the Department of Defense submitted to Congress for FY79 and subsequent fiscal years shall include data projecting the effect of the appropriations requested for material readiness requirements." In the supply community, this guidance is interpreted as how much will another dollar invested by Congress in spare parts buy in terms of Fleet readiness? Because of this Congressional requirement, most multi-echelon models have been developed to feature both a readiness performance measure and the multi-echelon supply system modeling.

Multi-echelon models which have been proposed for use or are currently being used by the military services have at least one of three purposes: (1) to tie budget dollars to readiness, (2) to determine the inventory levels at various echelons of supply given a readiness objective or (3) to predict readiness given the inventory levels (however determined) at each echelon of supply. These models vary in their structure, assumptions, objectives, procedures and data requirements. As a first step in understanding the advantages and disadvantages of multi-echelon inventory modeling, NAVSUPSYSCOM in reference 1 of APPENDIX A requested that FMSO examine and contrast the characteristics of the multi-echelon models used or proposed for use in the military services based on each model's available documentation. The results of this study will aid the Navy in choosing the multi-echelon inventory models which best fit the Navy's situation and needs.

FMSO obtained sufficient documentation for 17 multi-echelon models. The documentation used in this study is listed in references 2 through 32 of APPENDIX A. A matrix was developed to highlight and contrast the characteristics of the multi-echelon models studied. In addition to the matrix, abstracts were developed to discuss significant characteristics of the models which could not be put in the matrix and to highlight characteristics which distinguish the models from each other.

II. MODELS OVERVIEW

For each model reviewed in this study, TABLE I contains the model's acronym, who developed the model and to the best of our knowledge when, who the model was designed for, for what general purpose the model can be used and whether the model is analytic or a simulator. In this table, under "Purpose", the term optimization means that the model determines "optimal" inventory requirements for each echelon modeled subject to a constraint on system investment or performance. Evaluation, on the other hand, indicates that the model will provide an assessment of a given inventory or funding level. An analytic model is one whose mathematical or logical relationships are simple enough to use mathematical methods (such as algebra, calculus or probability theory) to obtain exact information on questions of interest. If the inventory system is too complex to model analytically, then a simulation model is often used. In a computer simulation, a model of the inventory system is evaluated numerically over the time period of interest and data are gathered to estimate the desired true characteristics of the model.

Abstracts were written for each of the models listed in TABLE I. The abstracts were developed to discuss significant characteristics of the models and to highlight characteristics which distinguish the models from each other.

TABLE I

MODELS REVIEWED

Model	Developed By	Designed For	Purpose	Type
Multi-Echelon Technique for Recoverable Item Control (METRIC)	RAND (1966)	Air Force	Optimization & Evaluation	Analytic
Multi-Echelon Technique for Recoverable Item Control - Modified (MOD-METRIC)	RAND (1973)	Air Force	Optimization & Evaluation	Analytic
Dynamic Multi-Echelon Technique for Re-coverable Item Control (DYNA-METRIC)	RAND (1981)	Air Force	Optimization & Evaluation	Analytic/ Simulator
Aircraft Availability Model (AAM)	LMI (1972)	Air Force	Optimization & Evaluation	Analytic
Wartime Assessment and Requirements System (WARS)	Air Force (1981)	Air Force	Optimization & Evaluation	Analytic
Selected Essential-Item Stockage for Availability Method (SESAME)	Army IRO (1980)	Army	Optimization & Evaluation	Analytic
Availability Centered Inventory Model (ACIM)	CACI (1981)	Navy	Optimization & Evaluation	Analytic
Multi-Item Multi-Echelon (MIME)	CNA (1981)	Navy	Optimization	Analytic
CAPLOG	Synergy (1982)	Navy	Evaluation	Analytic
Assessment of the Wholesale and Retail System (AWARES)	RAND (1984)	U.S. Aviation	Evaluation	Analytic
Ships Supply Support Study (S4)	FMSO (1973)	Navy	Evaluation	Simulator
Fleet Ballistic Missile (FBM) Weapons System Support Simulator	FMSO (1974)	Navy	Evaluation	Simulator
Aviation Afloat and Ashore Allowance Analyzer (5A)	FMSO & NADC (1977)	Navy	Evaluation	Simulator

TABLE I

MODELS REVIEWED (CONT'D)

Model	Developed By	Designed For	Purpose	Type
Simulation Package for Evaluation by Computer Techniques, Readiness, Utilization and Maintenance (SPECTRUM)	NADC (1978)	Navy	Evaluation	Simulator
Multi-Echelon Technique for Evaluating Operational Readiness (METEOR)	NAVPGSCOL (1983)	Navy	Evaluation	Simulator
TIGER	NAVSEASYSCOM (1979)	Navy	Evaluation	Simulator
Theater Simulation of Airbase Resources (TSAR)	RAND (1980)	Air Force	Evaluation	Simulator

A. <u>MULTI-ECHELON TECHNIQUE FOR RECOVERABLE ITEM CONTROL</u>. METRIC is an analytic multi-item, multi-echelon inventory model developed by the RAND Corporation in 1966 for Air Force repairable items. METRIC models a base-depot supply system. METRIC's application is by weapon system. The model determines base and depot stock levels for each item in order to minimize the sum of expected backorders on all items at all bases subject to a constraint on system investment or vice versa. Depot backorders are of interest only insofar as they affect base backorders. In addition to determining optimum stock levels, the model can take fixed stock levels for each item and allocate the stock between the bases and depot in order to minimize expected backorders. The model can also provide an assessment of the performance and investment cost for the system of any allocation of stock between the bases and depot.

METRIC assumes item demand follows a stationary compound Poisson distribution with a mean value estimated by a Bayesian procedure. When an item fails at the base level there is a probability, r, that it can be repaired at the base according to an arbitrary probability distribution of repair time and a probability, 1-r, that it must be returned to the depot for repair according to some other distribution. No indenture levels of parts are considered. Repair capacity is assumed to be unlimited and items are not batched for repair. All failed items are assumed to be repaired; i.e., METRIC assumes items are neither condemned nor lost in transit. Procurement is not considered in the model. There is no lateral resupply between bases. An (S-1,S) resupply policy is used at the bases. (An (S-1,S) resupply policy indicates that items are ordered as they are used ("use one, order one" policy)). Maximum or minimum stock levels may be specified for each base, the depot and the system before optimization or redistribution is performed.

B. <u>MULTI-ECHELON TECHNIQUE FOR RECOVERABLE ITEM CONTROL - MODIFIED</u>. MOD-METRIC is an analytic multi-item, multi-echelon inventory model developed by the RAND Corporation in 1973 for Air Force repairable items. As an extension of METRIC, MOD-METRIC explicitly includes hierarchical or indentured parts structure. The model allows two levels of parts to be considered, an assembly and its components. As in METRIC, MOD-METRIC models a base-depot supply system and its application is by weapon system. The model will determine the base and depot spare stock levels which minimize the expected base backorders for all assemblies subject to an investment constraint on the total dollars allocated to the assemblies and their components. Depot backorders are of interest only insofar as they affect base backorders. In addition to minimizing expected backorders for any system investment, the model can evaluate any distribution of stock and it can compute the optimal redistribution of stock among echelons. (See METRIC).

MOD-METRIC assumes item demand follows a stationary Poisson distribution whose mean is a random variable which is distributed according to a Gamma distribution. A percent base repairable rate is employed to determine where failed items will be repaired. Repair capacity is assumed to be unlimited and items are not batched for repair. All failed items are assumed to be repaired; i.e., MOD-METRIC assumes items are neither condemned nor lost in transit. Procurement is not considered in the model. There is no lateral resupply between bases. An (S-1,S) resupply policy is used at the base. Maximum or minimum stock levels may be specified for each base, the depot and the system before optimization or redistribution is performed.

C. DYNAMIC MULTI-ECHELON TECHNIQUE FOR RECOVERABLE ITEM CONTROL. DYNA-METRIC is a multi-item, multi-echelon analytic model, developed in 1981 by RAND Corporation, for Air Force repairable items. The model relates repairable spare parts supply levels and maintenance capacity to the readiness of aircraft by determining repairable requirements that maximize the probability that the Not Mission Capable Supply (NMCS) rate will not exceed a specific value at minimal cost. DYNA-METRIC's representation of the Air Force base-depot supply system closely resembles that of its predecessor, MOD-METRIC. DYNA-METRIC's application is by weapon system. The distinguishing feature of the model is its ability to deal with dynamic scenarios (for example, peacetime to wartime) in terms of demands placed on component repair and inventory support.

DYNA-METRIC assumes the resupply pipeline distribution is either Poisson or Negative Binomial. A percent base repairable rate is employed to determine where failed assets will be repaired. The model considers two levels of indentured parts. All failed items are assumed to be repaired; i.e., DYNA-METRIC assumes items are neither condemned nor lost in transit. Procurement is not considered in the model. For a particular scenario, the model addresses time variables such as planned flying hours, phased arrival of component resources, interruptions of transportation and repair capacity. For example, the daily demand rate is defined to be a function of time so that changes over time in parameters such as aircraft number and number of sorties per day per aircraft can be considered. DYNA-METRIC contains a cannibalization option which, when executed, consolidates the existing shortages onto the smallest number of airframes. The model is also equipped with a simulation option that can be employed to address situations where sudden increases in item failure cause demand for repair to exceed the capacity of the available base component repair resources (manpower, facilities, or test equipment). Otherwise, unlimited repair capacity is assumed. An (S-1,S) resupply policy is assumed.

D. THE AIRCRAFT AVAILABILITY MODEL. The Aircraft Availability Model is a multi-item, multi-echelon analytic model developed in 1972 by the Logistics Management Institute (LMI) for Air Force repairable items. The model uses marginal analysis techniques to develop a "shopping list" of candidates for repair and for procurement from highest to lowest benefit, in terms of aircraft availability per unit cost. The AAM thus can be used to maximize aircraft availability for a given budget or can be used to minimize the budget required to achieve a given level of aircraft availability. The AAM could, therefore, be used to develop a budget to allocate funds between repair and procurements or to determine item requirements. Since the AAM can handle multiple weapon systems simultaneously, tradeoffs of funds between different aircraft types can be made.

The AAM is a two-echelon (base, depot) model which allows up to five indenture levels of parts. The model assumes item demand follows a Poisson distribution whose mean, when not known, is modeled by the Gamma distribution. Therefore, the model uses a Negative Binomial pipeline distribution when mean demand is not known and a Poisson pipeline distribution when mean demand is known. Since the model does not address repairable components lost in transit, all components are assumed to be returned for repair. The AAM assumes that components can be condemned (because they are not economically repairable). There is no lateral resupply between bases. Repair capacity is assumed to be unlimited and items are not batched for repair. Procurement is addressed at the wholesale level. An (S-1,S) resupply policy is used at both echelons of supply.

E. WARTIME ASSESSMENT AND REQUIREMENT SYSTEM. WARS is an analytic multi-item, multi-echelon inventory model designed by the Air Force to quantify the aircraft spares requirement necessary to support any given wartime scenario and to assess the impact of specified stock levels on aircraft mission capability. Similar to other Air Force oriented models, WARS addresses supply operation in a base-depot supply system. WARS will calculate the expected number of NMCS aircraft resulting from given spare stock levels or will identify the minimum investment in spares required to support a specified expected NMCS goal. The model can also consider Partially Mission Capable (PMC) aircraft. In addition, the model will determine how much War Reserve Material (WRM) to buy when funds are available, and the wartime depot maintenance repair requirements.

WARS is a pipeline model and the distribution of items in the repair pipeline can be either Poisson or Negative Binomial. The model utilizes a Not Repairable This Station (NRTS) rate to determine the number of assets that must be cycled through depot level repair. WARS does not consider supply management of consumables. A hierarchical parts structure considering four levels of indenture (maximum) is addressed. The repair policy at both the organizational and depot levels is (S-1,S). This means that items are repaired as they are used and are not batched for repair. Repair capacity is assumed to be unlimited. Resupply policy is (S-1,S) at the base and depot levels. WARS is capable of addressing changes in level of operations over time since the model considers variations in pipeline asset level due to flying hour and failure rate changes. WARS provides both full and partial cannibalization options. Condemnation can occur at both base and depot levels. Procurement is addressed at the wholesale level.

F. <u>SELECTED ESSENTIAL-ITEM STOCKAGE FOR AVAILABILITY METHOD</u>. SESAME is an analytic multi-item, multi-echelon inventory model developed by the Army in 1980 for repairable components. SESAME determines through mathematical optimization, how many of each component to stock at each stockage point in the supply system, taking into account the potential impact of each backordered component on system downtime. SESAME's application is by weapon system. SESAME will stock to achieve any given weapon system target operational availability [A_o = MTBF(Mean Time Between Failures)/(MTBF+MTTR(Mean Time To Repair)+MLDT(Mean Logistic Delay Time))] at least cost. SESAME may also be used to find the best allocation of stock for a given budget. The SESAME model can, therefore, be used in both budget and production modes. In the budget mode, it can be used to develop curves showing the relationship between target operational availabilities and inventory investment. In the production mode, it can be used for requirements determination. SESAME computes stockage on lower indenture parts based on economic considerations, but does not explicitly model their contribution to system downtime.

SESAME assumes time between failures is exponential. Components cannot be shared by equipments and equipments cannot be partially degraded. SESAME allows for any number of echelons to be considered. Cannibalization and lateral resupply between bases are not considered in the model. SESAME assumes that not all components are returned for repair and that some components will not be economically repairable and therefore condemned. Outside procurement of components is considered by SESAME at the depot level. An (S-1,S) resupply policy is assumed. Components can be removed and repaired at all echelons. Repairable components are not batched for repair requests. Repair capacity is assumed to be unlimited.

G. AVAILABILITY CENTERED INVENTORY MODEL. The Availability Centered Inventory Model is a multi-item, multi-echelon, analytic model developed in 1981 by CACI and approved by the Chief of Naval Operations (CNO) for use in determining consumer level stockage quantities for selected equipments. ACIM's application is by weapon system. The objective of ACIM is to determine stock levels for all of the weapon system's items at all stockage facilities such that the expected operational availability (A_o = MTBF/(MTBF + MTTR + MLDT)) of the weapon system is maximized for a given inventory budget, or to find levels which achieve a given A_o at the least cost. This is accomplished by minimizing the sum of the time-weighted expected backorders for the assemblies installed directly on the weapon system at the ship or consumer level.

ACIM assumes item demand follows a stationary Compound Poisson distribution. The model considers both repairable and consumable items. Theoretically, ACIM allows for any number of echelons of supply or indenture levels of parts to be modeled. Since the model does not address repairable components lost in transit, all components are assumed to be returned for repair. ACIM allows components to be not economically repairable (condemned) at both the intermediate and depot levels of maintenance. Repair capacity is assumed unlimited and items are not batched for repair. An (S-1,S) resupply policy is assumed at all echelons of supply.

H. MULTI-ITEM MULTI-ECHELON. MIME is an analytic, multi-item, multi-echelon inventory model developed for the Navy by the Center for Naval Analysis. The MIME model minimizes investment in spares subject to a target operational availability for a weapon system or vice versa. Up to two weapon systems can be handled at a time. Partial degradation of a weapon system is not considered; however, redundancy of an assembly within a weapon system can be accounted for.

That is, given that a particular assembly has a population of N for a given weapon system, MIME can account for the fact that only K (K < N) of the N assemblies are needed to operate the weapon system. A supply and maintenance network is input into MIME. A network consists of some or all of the following supply and maintenance echelons:

- Depots which are assumed to be co-located with wholesale supply points.

- Intermediate Maintenance Activities (IMAs) which are assumed to be co-located with retail supply points.

- Forward Location Inventories (FLIs) where some repair capability might be provided.

- Motherships where some repair capability might be provided.

- Ships which contain retail level inventories.

The MIME model assumes that demand for each part at a support site is given by a stationary Poisson distribution. An (S-1,S) resupply policy is used with no lateral resupply and no cannibalization. Assemblies are not batched for repair and repair capacity is assumed to be unlimited. If an assembly is beyond depot level meintenance, the depot requisitions a replacement from a manufacturer.

I. <u>CAPLOG</u>: CAPLOG is an analytic, multi-item, multi-echelon, assessment model that was developed for the Navy by Synergy Corporation in 1982. The model provides an evaluation of mission capability and sustainability by weapon system. The model is capable of addressing large-scale supply problems in an expedient manner. Although CAPLOG was designed for the Navy, the model's treatment of supply and repair processes more closely emulates the Air Force environment; for example, CAPLOG models a base/depot supply system. Only repairable item management is addressed in the model. Each model run includes operational evaluations for a peacetime scenario followed by a wartime scenario. During peacetime operation demand is stationary. When wartime operation commences, demand can fluctuate due to changes in number of aircraft in the war force which directly alters flying hour programs. CAPLOG is separated into four modules:

- Mission Degradation Module which identifies the spares that cause mission failures and the percent of required missions flown.

- Shortfall/Buy Module that determines the total repairable spares budget required to support a given flying hour program.

- Pipeline Fill Module that calculates the dollar value of spares that have failed and the dollar value of spares necessary to compensate for items in the repair pipeline.

- Readiness Module that measures the state of operational readiness of a group of aircraft and determines the number of times during the war that specific spares cause NMCS.

In the CAPLOG model, average item demand is developed using failure rates (historical observations), item quantities installed per aircraft (totaled by aircraft type), and flying hour programs (by aircraft type). An (S-1,S) reorder policy is used. Both base and depot are assumed to have unlimited repair capacity and items are not batched for repair. Condemnations can occur at either base or depot. Initial supply levels are provided as inputs and assets are distributed uniformly throughout the repair pipelines. Cannibalization occurs at the organizational level (base) and is an integral part of the model since a downed aircraft is viewed as an assemblage of available spare parts. Procurement is addressed at the wholesale level.

J. ASSESSMENT OF THE WHOLESALE AND RETAIL SYSTEM. AWARES is an analytic, multi-item, multi-echelon model designed to assess the impact of support system resources for repairable components on operational force performance during dynamic scenarios. AWARES consists of two modules, a workload generator and a wholesale supply and depot level repair module. The purpose of the workload generator is to calculate two time-varying quantities: (1) the maximum flow of broken components from the theater to the depot and (2) the minimum required issues of serviceable components from wholesale so that the operational forces may perform their required mission.

The maximum flow of broken components from the theater to the depot is driven by user-specified flying programs. The model assumes that broken components removed from aircraft at the flight lines are sent back through the several support echelons with some fraction (possibly zero) being repaired at each one. Components which reach an intermediate level, but cannot be repaired there, and are not lost or condemned, will ultimately arrive -- after transportation and administrative delays -- at the depot for repair.

Components are not batched for repair. Repair capacity at each echelon is assumed to be unlimited. Cannibalization is allowed at all echelons of repair.

The minimum required issues of serviceable components from wholesale are driven by three criteria: (1) the minimum number of aircraft needed to accomplish the flying program, (2) any additional requirement for airworthy aircraft for contingencies and (3) requirements for prepositioned war reserve material. An echelon will requisition a replacement component an order-and-ship time prior to the anticipated time that one of these three criteria will be violated. There is no lateral resupply.

The wholesale module calculates both the required wholesale stock levels and, given the stock levels, the minimum required depot repairs of each component.

K. SHIPS SUPPLY SUPPORT STUDY. S4 is a multi-item, multi-echelon simulation model, developed in 1973 by FMSO, to relate supply support dollar outlays to Fleet capability. The S4 model, which was developed based on the Sixth Fleet material support system, can be separated into the following four modules:

- The Afloat Simulator Module models ship supply support from the ship's storeroom, the Material Control Officer (MATCONOFF) screening, and an AFS (Combat Store Ship).

- The Continental United States (CONUS) Simulator Module models ship supply from the Point of Entry (POE) activity (NSC Norfolk) and from referral, backordering, spot-buying, and spot-repairing by the Inventory Control Point (ICP).

- The Process Analyzer uses engineered or estimated time standards to model the requisition and material flow within an organization and various doctrines concerning batching, scheduling, and transporting to produce a statement of the probability that a requisition of material will be processed through an organization in a specified time.

- The Synthesizer combines the outputs of the Inventory Simulators and Process Analyzer to produce estimates of (1) the distribution of requisition response time, (2) workload (issues, receipts, orders, and items carried), (3) inventory levels, and (4) average, incremental, and marginal costs.

S4 can generate the following performance measures:

- The Gross Supply Availabilities at the different supply echelons.

- The Throughput Time for each echelon - the time required for a requisition and the associated material shipment to complete the several legs of their journey from the mechanic to the echelon having stock and back to the mechanic.

- The Requisition Response Time as the mechanic views it.

- The Supply Response Time - the time required to collect all the parts needed for a corrective maintenance action.

- The Operational Availability, or up-time, of a particular nomenclature of equipment.

S4 models four echelons of supply support. S4 does not address an indentured parts structure. Demands for the afloat segment are based on either empirical data or are generated based on the Stuttering Poisson or the Binomial distribution. Demands for the CONUS segment are generated using the same methods with the exception that the Binomial distribution is not used. Changes in the level of operations can be reflected by the input demand stream. S4 is designed to address requirements for ships' parts while demands for aviation material are not considered. The management or both repair parts and consumables that are needed for equipment maintenance is considered. The resupply policy is (s,S) at all echelons. An (s,S) resupply policy indicates that a reorder level and reorder quantity are used. Repair occurs only at the wholesale level. The repair policy is (s,S) which means that an economic repair quantity is used. Procurement and condemnation are also considered at the wholesale level. S4 includes a "carcass-not-returned" rate to enable the user to account for Not Ready For Issue (NRFI) material lost in transit to the depot repair site. Lateral resupply is permitted at the organizational level.

L. FBM WEAPON SYSTEM SUPPORT SIMULATOR. The FBM Weapon System Support Simulator is a two echelon, multi-item simulator developed by FMSO in 1974 which models supply operation at the tender and CONUS level for Fleet Ballistic Missile (FBM) submarines. The system being simulated consists of: (1) 31 Poseidon FBM submarines, (2) three supporting tenders and (3) one CONUS stocking activity which performs stock point and inventory control point functions. The goal of the simulator is to determine the effectiveness of the supporting tender and

CONUS activities in satisfying refit demands where effectiveness is measured in terms of impact on: (1) mission capability impairment, (2) requisition effectiveness, (3) investment level, (4) tender workload, (5) transportation system, (6) CONUS workload and (7) CONUS response time.

The driving force in the simulator is submarine demands which are based on either empirical data or are generated using either the Stuttering Poisson or the Binomial distribution. Changes in the level of operations can be reflected by the demand stream. Management of both repair parts and consumables is addressed in the model.

Repair is accomplished only at the depot (CONUS) activity. Repair capacity is assumed to be unlimited and items are not batched for repair. A fraction of all repairable items are returned to the depot for repair based on their carcass return rates. Repairable items may also be condemned at the depot. An (s,S) resupply policy is followed at both echelons of supply. Demands at the tender level may be satisfied through lateral resupply by referring the demand to another tender. The tender's requisitioning objective and reorder point are initiated based on their computed load list quantities. Items may be added to the range of items the tender carries and levels of stock may be increased on items carried by the tender based on item demand characteristics.

M. AVIATION AFLOAT AND ASHORE ALLOWANCE ANALYZER. 5A is a multi-item, multi-echelon simulation model developed in 1977 by FMSO to model naval aviation supply support. The 5A system is comprised of four different models:

- The Carrier Support Simulator which emulates carrier supply and Aircraft Intermediate Maintenance Department (AIMD) operations.

- The Stock Point Simulator which emulates the supply system operation of a stock point (e.g. NSD Subic Bay).

- The Wholesale Inventory Simulator which emulates the Transaction Item Reporting (TIR) portion of the Naval Aviation Supply Distribution and Requisitioning System. This includes ICP procedures and supply and depot level repair procedures at appropriate field activities.

- The Synthesizer which applies outputs from each of the above models along with time distributions and probabilities of occurrence to compute Requisition Response Time.

Collectively, the 5A models provide a means to determine the impact on Requisition Response Time of proposed policy/procedural changes. Individually, the models can be used to evaluate a wide variety of decisions at specific echelons of supply. 5A is detailed in its representation of naval aviation supply support. Each echelon model exhibits the characteristic specific to that level of supply in the real world. 5A models four echelons (carrier, intermediate, stock point and ICP) of supply support.

At the organizational level, a three tiered indentured parts structure is addressed. The Stock Point and Wholesale Inventory Simulators are designed to accept external demand streams. Changes in level of operations can be addressed by establishing demand patterns that reflect the same. The Carrier Simulator generates demands based on a Poisson distribution. Demand generation for each supply echelon is independent. A "carcass-not-returned" rate is included in the wholesale portion of 5A to address the loss of NRFI assets while in transit to the depot repair site. A carcass can be deemed not economically repairable (condemned) at the depot level. Purchase actions are considered at the wholesale level. The repair policy is (S-1,S) at both the organizational and depot levels. The resupply policy is (s,S) at all echelons. Cannibalization is addressed at the organizational level. Supply management of both repairables and consumables is modeled.

N. <u>SIMULATION PACKAGE FOR EVALUATION BY COMPUTER TECHNIQUES, READINESS, UTILIZATION AND MAINTENANCE</u>. SPECTRUM is a multi-item, multi-echelon simulation model developed in 1978 by the Naval Air Development Center (NADC). SPECTRUM consists of a series of aviation maintenance support simulation models which are capable of projecting readiness values for a collection of naval airborne weapon systems at a single site as a function of their logistics support system. SPECTRUM was developed by NADC using a modular concept. The modules are classified into two groups, the Projected Readiness Implications of Support and Maintenance (PRISM) module and the Review and Evaluation of Turnaround and Inventory at Naval Air Rework Facilities (NARF) Activities (RETINA) module. The PRISM group simulates organizational and intermediate level maintenance as well as local aviation supply. The PRISM group consists of the following four modules which can be run independently or collectively:

- Organizational Policy and Technique Improvement, Computer Simulation (OPTICS) simulates aviation organizational level maintenance operations.

- Intermediate Maintenance Activity, Generic Evaluator (IMAGE) simulates aviation intermediate level maintenance of Weapon Replaceable Assemblies

(WRAs) within an Aircraft Intermediate Maintenance Department (AIMD).

- Performance Evaluation of Engine Replacement (PEER) simulates the flow of engines in the AIMD complex.

- Local Aviation Supply Efficiency Review (LASER) simulates supply activity relative to WRA repair at the intermediate maintenance level.

The RETINA module simulates the gross features of the component repair system of the NARFs.

SPECTRUM simulates three echelons of support and can handle two indenture levels. Supply management of both repairables and consumables is modeled. Repair of a component can be delayed by a lack of manpower and/or parts. Repairable components are not batched for repair. Cannibalization occurs at the organizational level and aircraft can be partially degraded. SPECTRUM uses an (s,S) resupply policy with outside procurement considered at the wholesale level.

O. MULTI-ECHELON TECHNIQUE FOR EVALUATING OPERATIONAL READINESS. METEOR is a multi-item, multi-echelon simulation model developed in 1983 by the Naval Postgraduate School (NAVPGSCOL). METEOR has two primary program modules, TIGER and MULTE. TIGER, the simulation model developed by the Naval Sea Systems Command, is the equipment configuration and hardware system evaluation module which generates component failures (demands) during an endurance period and calculates readiness, reliability and availability statistics based on the equipment's operational status. MULTE is the supply effectiveness module which given a demand, generated by TIGER, will process the requirement through the supply echelons, order replacements for stock when necessary and return a supply response time to TIGER. Because of the modular design, METEOR is able to (1) compare and evaluate the relative performance of analytic multi-echelon inventory models and (2) estimate weapon system readiness as a function of the system configuration, the equipment reliability, the repair process, the mission scenario, and the logistics support system. (For more details on TIGER, see TIGER abstract.)

METEOR models repairables of variable indenture levels and consumables within a supply system of up to five echelons. A nonstationary Poisson demand distribution is assumed in the model. Redundancy of components can be addressed in METEOR. The repair policy is user specified at the depot level. The model allows the user to input an Economic Repair Quantity (ERQ) and a "*carcasses-not-returned*" rate. No repair policy is modeled for the organizational or intermediate levels of maintenance. All echelons of supply have an (s,S) resupply policy where the user inputs the reorder point, 's', and the high inventory limit, 'S'. Lateral resupply is allowed. Procurement is addressed only at the wholesale level.

P. <u>TIGER</u>. TIGER is a multi-item, multi-echelon simulation model developed by the Naval Sea Systems Command. TIGER is the generic name for a family of computer programs which evaluate a system's reliability, availability, and readiness over an endurance period or mission scenario. The complexity of the system being evaluated can range from a single equipment, such as a radar, to a complete weapon system, such as a ship. The estimated performance measures calculated by TIGER are:

- Reliability - the probability that a system performs satisfactorily for an entire mission.

- Instantaneous Availability - The probability that a system is operational at a specific point in time where operational means that the system is not down.

- Average Availability - the probability that a system is operational at a random point in time.

- Readiness - the probability that a system is in satisfactory operating condition at a random point in time where satisfactory operation occurs when there is neither a mission abort or a system down.

TIGER models three echelons of supply (ship, tender, and depot). Both consumable and repairable logistic support are considered. TIGER assumes item demand follows a Poisson distribution. The mission scenario is user defined by a sequence of operational phases of predetermined durations, where there can be up to six different operational phase types, such as cruising and combat phases for a shipboard environment. TIGER can theoretically handle an indefinite number of indenture levels which allow TIGER to model virtually an unlimited range of equipment configurations, from very broad system representations to the minute details of piece parts. TIGER can handle redundancy of parts through the equipment configuration definition. TIGER assumes that equipment can only fail when operating and that equipment time to failure and equipment time to repair are distributed exponentially. Since no maintenance mode is modeled; condemnation, cannibalization, repair items lost in transit, and a repair policy are not addressed. The initial number of spares at each of the three supply echelons are inputs to TIGER and no additional resupply of spares is considered. When the mission allowable downtime is exceeded or when spares are depleted, the simulated mission is aborted and the system will not recover to operational for the remainder of the mission. An optional extension of the model, TIGER/MANNING, deals with manpower reserves. By selecting the TIGER/MANNING option, the user can study the effect of corrective maintenance staffing on system reliability, availability and readiness.

Q. THEATER SIMULATION OF AIRBASE RESOURCES. TSAR is a multi-item, multi-echelon simulation model designed by RAND for the Air Force. TSAR enables the user to assess the interrelations among available resources and the capability of the airbases to generate aircraft sorties in a dynamic, rapidly evolving wartime environment. There are 11 possible classes of resources addressed: the aircraft, the aircrews, the ground personnel, ground support equipment and other test equipment, aircraft parts, aircraft shelters, munitions, TRAP (Tank, Rack, Adaptors and Pylons), fuels, building materials, and airbase facilities. Asset accounting for each of these 11 resource classes, and for each type within each class, permits assessment of a broad range of policy options that could improve the efficiency of resource utilization on a theater-wide basis.

TSAR can assess problems of varying degrees of complexity. The user must select the features of the model which are applicable to the scenario in question. For example, the user can choose to represent a single airbase, a set of independent airbases, or a set of interdependent airbases. However, the more comprehensive the scenario, the greater the extent of input data that must be developed by the user to support the model. If the user elects to simulate the effect of losses to various on-base resources and the damage to runways, taxiways, buildings and other facilities, the TSARINA model is used in conjunction with TSAR. TSARINA generates and stores airbase damage data in the exact format required by TSAR.

TSAR considers three echelons of supply (depot, Central Intermediate Repair Facility (CIRF), and airbases) and two indenture levels of repairables (Line Replaceable Units (LRUs) and Shop Replaceable Units (SRUs)). Condemnation at the organizational and intermediate levels, lateral resupply, and partial degradation are all addressed in the model. Carcasses returned do not equal demand, since allowance is made for shipments lost en route. Cannibalization can occur at the organizational and intermediate level if the required part is not available in supply. Procurement is not considered at any level of supply. The organizational and intermediate maintenance levels repair policy is (S-1,S) which means that batching of repair requests is not allowed. There is no repair policy modeled at the depot level. Where repair occurs depends not only on the complexity of the repair but also on the backlog of repairs at the repair facility. Delay in repair because of unavailable resources is allowed.

III. MODELS COMPARISON

This section is divided into two parts: Matrix Comparison of the Models and Inferences Drawn from the Matrix.

A. MATRIX COMPARISON OF THE MODELS. TABLE II contains a matrix that was developed to highlight the model's structure, assumptions, objectives and procedures. (APPENDIX B contains additional information about each model.) The information contained in the matrix was drawn from each model's documentation. None of the models were exercised with test data. Explanation of the matrix column titles follows:

1. General. Sections marked General I, II, III, and IV contain general characteristics of the models.

Developed by: self-explanatory

Designed for: self-explanatory

Purpose: self-explanatory

Computer Language: self-explanatory

Analytic/Simulation: The Analytic/Simulation column indicates whether the model was classified as an analytic model or a simulation model. For a discussion of these two types of models see Section II of this report.

Echelons: The Echelons column indicates the maximum number of echelons the model is currently designed to handle.

Indenture Levels: The Indenture Levels column indicates the maximum number of indenture levels the model is currently designed to handle.

Objective Function: For models with an optimization capability, the Objective Function column states the model's objective function. For models with only an evaluation capability, the Objective Function column states that the model is an assessment model. Assessment models generally take one of two forms: either a very detailed supply oriented micro analysis that usually yields some measure of equipment readiness or a broad based, nondetailed macro analysis that usually ties dollars to readiness.

Optimization Technique: For models with an optimization capability, the Optimization Technique column states the model's optimization technique. For models without an optimization capability, the Optimization Technique column is left blank.

Minimum Stock Levels: A "Y" in the Minimum Stock Levels column indicates that minimum levels of stock can be specified for at least one echelon.

Maximum Stock Levels: A "Y" in the Maximum Stock Levels column indicates that maximum levels of stock can be specified for at least one echelon.

Repairable Items: A "Y" in the Repairable Items column indicates that the model is designed to handle items which, after undergoing repair or overhaul, can be reissued to meet demand.

Consumable Items: A "Y" in the Consumable Items column indicates that the model is designed to handle items which when issued represent permanent losses to the system in a more explicit manner than assuming the item is condemned when failed.

Change in Level of Operations Over Time: A "Y" in the Change in Level of Operations Over Time column indicates that the model has some capability to handle dynamic scenarios through time dependent modeling and/or parameters.

Weapon System Oriented: A "WS" in the Weapon System Oriented column indicates that the model is run for a set of items oriented to a particular weapon system. An "N" indicates that the model is run for a general set of items in the supply system which are not necessarily tied to any particular weapon system. A "WS(s)" in the Weapon System Oriented column indicates that the model can handle more than one weapon system.

2. Assumptions. Sections marked Assumptions I and II contain assumptions made by the models.

Distribution of Interest: The Distribution of Interest column indicates whether the model is deterministic or stochastic. If the model is deterministic the Distribution of Interest column is blank. If the model is stochastic the Distribution of Interest column indicates whether the model is based on the demand or pipeline distribution. In general, simulation models are based on the demand distribution while analytic models are based on the pipeline distribution. The pipeline distribution models the number of items in the repair or resupply processes.

Demand Distribution: The Demand Distribution column specifies the probability distribution(s) that can be used for models whose distribution of interest is demand. "Empirical" indicates that the model uses a demand stream input into the model for demand data.

Pipeline Distribution: The Pipeline Distribution column specifies the probability distribution(s) that can be used for models whose distribution of interest is pipeline.

Distribution Is Stationary: A "Y" in the Distribution Is Stationary column indicates that the parameters of the distribution of interest are not time dependent and are, therefore, stationary over time.

Lateral Resupply: A "Y" in the Lateral Resupply column indicates that the model allows a supply point to be resupplied from a supply point within the same echelon not just from a supply point in a higher echelon.

Where Repair Is Accomplished Depends on Complexity: A "Y" in the Where Repair Is Accomplished Depends on Complexity column indicates that where a repair is accomplished depends on the complexity of the repair and the capability of the repair facility.

Where Repair Is Accomplished Depends on Backlog: A "Y" in the Where

Repair Is Accomplished Depends on Backlog column indicates that the decision of where a repair is to be accomplished depends on the backlog of repairs at the repair facility. That is, if the repair facility is busy it may be more advantageous to repair a carcass at another repair facility.

Carcasses Turned-In Equals Demand: An "N" in the Carcasses Turned-In Equals Demand column indicates that the model can handle the fact that not all repairable carcasses are returned to the repair facility. That is, a NRFI carcass can be "lost in transit".

Redundancy: A "Y" in the Redundancy column indicates that the model can handle some type of redundant design within a system.

Partial Degradation: A "Y" in the Partial Degradation column indicates that the model can handle some type of partial degradation of a weapon system. An example of partial degradation of a weapon system would be if a weapon system, which was capable of three types of missions, could perform only two of the three missions because of a "hole" in the weapon system. A "hole" exists when an item installed directly on the weapon system has been removed but not replaced. When partial degradation is not considered a weapon system is either up or down. If there are any "holes" in the weapon system it is down. If there are no "holes" in the weapon system it is up.

3. Maintenance. There are five sets of columns under Maintenance I and II which deal with maintenance decisions. Each column is divided into three sections denoting the decision at the organizational level of maintenance, the intermediate level of maintenance and the depot level of maintenance. Note: N/M in the matrix stands for not modeled.

Condemnation: A "Y" in a Condemnation column indicates that the model allows a repairable item to be not economical to repair and, therefore, condemned at that echelon.

Repair Begins Immediately: A "Y" in a Repair Begins Immediately column indicates that the model assumes that repair begins immediately once a decision to repair is made at that echelon. That is, the repair does not have to wait for resources (for example: parts and/or personnel) to become available. This is often referred to as unlimited repair capacity.

Independent Repair Times: A "Y" in an Independent Repair Times column indicates that the model assumes that the repair time of an item is independent of the repair time of any other item at that echelon. An example of a dependent repair time follows: Suppose repair of Item A is halted until Item B has finished repair because resources needed to repair Item A are needed to repair Item B which has a higher priority. Then Item A's repair time is dependent on Item B's repair time. Note: If an unlimited repair capacity is assumed then the repair times are independent.

Repair Policy: The Repair Policy columns indicate what type of repair policy is modeled. An (S-1,S) repair policy indicates that items are repaired as they are used, that is, items are not batched for repair. An (s,S) repair policy indicates that there is a repair level and a repair quantity.

Cannibalization: A "Y" in a Cannibalization column indicates that some type of cannibalization is considered in the model at that echelon.

4. Supply. There are two sets of columns under supply which deal with resupply decisions. Each column is divided into three sections denoting the decision at the consumer level of supply, the intermediate level of supply and the wholesale level of supply.

Resupply Policy: The Resupply Policy columns indicate what type of resupply policy is modeled. An (S-1,S) resupply policy indicates that items are ordered as they are used ("use one, order one" policy). An (s,S) resupply policy indicates that a reorder level and reorder quantity are used.

Outside Procurement Considered: A "Y" in an Outside Procurement Considered column indicates that the model considers procurement from a source outside of the supply system at that echelon.

Note: The last row of the matrix, which is entitled 'U. S. Navy', represents the "real world". That is, the response found in the last row represents the Navy's current policy. For example, a 'Y' in the lateral resupply column for the U. S. Navy row means that lateral resupply is allowed within the U. S. Navy supply system.

TABLE II

MATRIX COMPARISON OF THE MULTI-ECHELON MODELS

GENERAL I

MODELS	DEVELOPED BY	DESIGNED FOR	PURPOSE
METRIC	RAND (1966)	Air Force	Optimization; Redistribution; Evaluation . determine optimal stock levels for each item subject to a constraint on system investment or system performance.
MOD-METRIC	RAND (1973)	Air Force	. take fixed stock levels of each item and optimally allocate the stock between bases and depot. . provides an assessment of performance and investment cost for the system of any allocation of stock between the bases and depot.
DYNA-METRIC Version 3.04	RAND (1981)	Air Force	Optimization; Evaluation . compute time dependent inventory levels necessary to support specified level of operational performance. . assess time dependent mission readiness given pre-determined mix of resources.
AAM	Logistics Management Institute (LMI)(1972)	Air Force	Optimization; Evaluation . used in an interim model to allocate budgets for procurement of replenishment spares and for requirements determination. . preparation and justification of Program Objective Memorandum (POM) and Budgets.

MODELS	DEVELOPED BY	DESIGNED FOR	PURPOSE
WARS	Air Force (1981)	Air Force	To determine the following: . aircraft recoverable item spares required to support given war scenarios. . aircraft recoverable item spares for WRM stock to buy when funds are available. . measure the impact of specific asset positions on ability to fly the war program. . depot level maintenance repair requirements for aircraft recoverable item spares.
SESAME	ARMY IRO (1980)(DARCOM Provisioning Technical Working Group)	Army	Optimization; Evaluation . determine optimal stock levels for each item subject to a weapon system target availability. . to develop curves showing the relationship between target operational availabilities and inventory investment.
ACIM	CACI (1981)	Navy	Optimization; Evaluation . compute stock levels for all items in the parts breakdown of an equipment and at all stockage facilities in a multi-echelon support system.
MIME	CNA (1981)	Navy	To determine the optimal initial provisioning of WRA spares at various inventory points where optimal is defined as the minimal cost initial provisioning needed to keep each weapon system operationally available a specified percentage of time.

GENERAL I (CONT'D)

MODELS	DEVELOPED BY	DESIGNED FOR	PURPOSE
CAPLOG	Synergy (1982)	Navy	Assessment of mission capability and sustainability by weapon system.
AWARES	RAND (1984)	U.S. Aviation	To assess the impact of support system resources (spares; repair; transportation) on operational force performance during dynamic scenarios.
S4	FMSO (1973)	Navy	Assess impact of inventory related policy or procedural change on level of gross supply availability (operational readiness).
FBM	FMSO (1974)	Navy	To determine the effectiveness of the supporting tender and CONUS activities in satisfying FBM submarine refit demands where effectiveness is measured in terms of impact on: (1) mission capability impairment, (2) requisition refit effectiveness, (3) investment level, (4) tender workload, (5) transportation system, (6) CONUS workload, and (7) CONUS response time.
5A	FMSO (1977) . Wholesale . Stock Pt. . Synthesizer NADC . Carrier (IMAGE, LASER)	Navy	Assess impact of inventory related policy or procedural change on level of supply availability (operational readiness).
SPECTRUM	NADC (1978)	Navy (NAVAIRSYSCOM)	To project readiness values for a collection of naval airborne weapon systems at a single site as a function of their total logistics support system.

GENERAL I (CONT'D)

MODELS	DEVELOPED BY	DESIGNED FOR	PURPOSE
METEOR	NAVPGSCOL (1983)	Navy	To assess multi-echelon inventory models and the supply system's impact on weapon's system performance in a shipboard environment.
TIGER	NAVSEASYSCOM (1979)	Navy	To evaluate a system's reliability, readiness and availability over an endurance period.
TSAR	RAND (1980)	Air Force	To assess the interrelationship among available resources and the capability of the airbases to generate aircraft sorties in a dynamic wartime environment.

GENERAL II

MODELS	COMPUTER LANG.	ANAL/ SIMULATOR	ECHELONS	INDENTURE LEVELS
METRIC	FORTRAN	Analytic	2	1
MOD-METRIC	FORTRAN	Analytic	2	2
DYNA-METRIC	FORTRAN	Anal/Sim-ulator	2	2
AAM	FORTRAN	Analytic	2	5
WARS	FORTRAN	Analytic	2	4
SESAME	FORTRAN	Analytic	Variable	1
ACIM	PL1	Analytic	Variable	Variable
MIME	FORTRAN	Analytic	5	1
CAPLOG	FORTRAN	Analytic	2	1
AWARES	FORTRAN	Analytic	Variable	Variable
S4	SIMSCRIPT II.5	Simulator	4	1
FBM	SIMSCRIPT I.5	Simulator	2	1
5A	SIMSCRIPT II.5 . Wholesale . Stock Pt. GPSS . IMAGE . LASER	Simulator	4	3 (only at carrier level)
SPECTRUM . PRISM .. OPTICS .. IMAGE .. PEER .. LASER . RETINA	 GPSS V GPSS/360 GPSS/360 GPSS GPSS V/6000	Simulator	3	2

GENERAL II (CONT'D)

MODELS	COMPUTER LANG.	ANAL/ SIMULATOR	ECHELONS	INDENTURE LEVELS
METEOR	FORTRAN IV	Simulator	5	1
TIGER	FORTRAN IV	Simulator	3	Variable
TSAR	FORTRAN IV	Simulator	3	2
U. S. Navy	N/A	N/A	3	6

GENERAL III

MODELS	OBJECTIVE FUNCTION	OPTIMIZATION TECHNIQUE
METRIC	Minimize expected consumer backorders subject to an investment constraint.	Marginal Analysis & Lagrangian Techniques
MOD-METRIC	Minimize expected consumer backorders for end items subject to an investment constraint.	Marginal Analysis & Lagrangian Techniques
DYNA-METRIC	Minimize investment in spare parts such that the probability that the Not Mission Capable Rate (NMCR) will not exceed a specified value is a pre-specified confidence level.	Marginal Analysis & Lagrangian Techniques
AAM	Maximize aircraft availability subject to a dollar allocation constraint or minimize the cost to achieve a target aircraft availability by producing optimum shopping lists and optimum repair strategies.	Marginal Analysis
WARS	Minimize expected NMCS subject to an investment constraint and vice versa.	Marginal Analysis
SESAME	Minimize investment subject to a target availability which equals MTBF/(MTBF + MTTR + MLDT).	Lagrangian Techniques
ACIM	Select a minimum cost set of spares for a system so that the system will achieve a given A_o (MTBF/(MTBF+MTTR+MLDT)) target or for a given spare part budget select a set of spares that will produce maximum A_o for the system.	Marginal Analysis & Lagrangian Techniques

GENERAL III (CONT'D)

MODELS	OBJECTIVE FUNCTION	OPTIMIZATION TECHNIQUE
MIME	Minimize investment in spares subject to a target operational availability for each weapons system and vice versa.	Marginal Analysis
CAPLOG	Assessment model (MACRO)	
AWARES	Assessment model (MACRO)	
S4	Assessment model (MICRO)	
FBM	Assessment model (MICRO)	
5A	Assessment model (MICRO)	
SPECTRUM	Assessment model (MICRO)	
METEOR	Assessment model (MICRO)	
TIGER	Assessment model (MACRO)	
TSAR	Assessment model (MACRO)	

GENERAL IV

MODELS	MIN STOCK LEVELS	MAX STOCK LEVELS	REPAIR-ABLE ITEMS	CONSUM-ABLE ITEMS	CHANGE IN LEVEL OF OPERS. OVER TIME	WEAPON SYSTEM ORIENTED
METRIC	Y	Y	Y	N	N	WS
MOD-METRIC	Y	Y	Y	N	N	WS
DYNA-METRIC	Y	N	Y	N	Y	WS
AAM	Y	N	Y	N	N	WS(s)
WARS	Y	N	Y	N	Y	WS
SESAME	Y(.42)	N	Y	N	N	WS
ACIM	Y(COSAL)	N	Y	Y	N	WS
MIME	Y	N	Y	N	N	WS
CAPLOG	N/A	N/A	Y	N	Y	WS(s)
AWARES	N/A	N/A	Y	N	Y	WS(s)
S4	Y(COSAL; FILL)	N	Y	Y	Y	N
FBM	Y(Load List)	N	Y	Y	Y	WS
5A	Y(AVCAL)	N	Y	Y	Y	N
SPECTRUM	N/A	N/A	Y	Y	Y	WS(s)
METEOR	N/A	N/A	Y	Y	Y	WS
TIGER	N/A	N/A	Y	Y	Y	WS
TSAR	Y	N	Y	Y	Y	N/WS(s)
U.S. Navy	Y	Y	Y	Y	Y	N/WS(s)

ASSUMPTIONS I

MODELS	DISTRIBUTION OF INTEREST	DEMAND DIST.	PIPELINE DIST	DIST. IS STATIONARY	LATERAL RESUPPLY	WHERE REPAIR IS ACCOMPLISHED DEPENDS ON:	
						COMPLEXITY	BACKLOG
METRIC	Pipeline		Neg Bin	Y	N	Y	N
MOD-METRIC	Pipeline		Poisson	Y	N	Y	N
DYNA-METRIC	Pipeline		Poisson; Neg Bin; Binomial	N	N	Y	N
AAM	Pipeline		Poisson; Neg Bin	Y	N	Y	N
WARS	Pipeline		Poisson; Neg Bin	N	N	Y	N
SESAME	Pipeline		Poisson	Y	N	Y	N
ACIM	Pipeline		Poisson; Neg Bin	Y	N	Y	N
MIME	Pipeline		Poisson	Y	N	Y	N
CAPLOG	None				N/A	Y	N
AWARES	None				N	Y	N
S4	Demand	Empirical; Stuttering Poisson; Binomial		N	Y	N/A	N/A
FBM	Demand	Empirical; Stuttering-Poisson; Binomial		N	Y	N/A	N/A
5A	Demand	Wholesale-Empirical Stock Pt.-Empirical; Consumer-Poisson		N; Y	N	Y	N
SPECTRUM	Demand	Poisson		N	N	Y	N
METEOR	Demand	Poisson		N	Y	N/A	N/A
TIGER	Demand	Poisson		N	N	N/A	N/A
TSAR	None				Y	Y	Y
U.S.Navy	N/A	N/A	N/A	N/A	Y	Y	Y

ASSUMPTIONS II

MODELS	CARCASSES TURNED IN EQUALS DEMAND	REDUNDANCY	PARTIAL DEGRADATION
METRIC	Y	N/A	N/A
MOD-METRIC	Y	N/A	N/A
DYNA-METRIC	Y	N	N
AAM	Y	N	N
WARS	Y	N	Y
SESAME	N	N	N
ACIM	Y	N	N
MIME	Y	Y	N
CAPLOG	Y	N	N
AWARES	N	N	N
S4	N	N	N
FBM	N	N/A	Y
5A	N	N	N
SPECTRUM	Y	N	Y
METEOR	N	Y	N
TIGER	N/A	Y	N
TSAR	N	N	Y
U.S.Navy	N	Y	Y

MAINTENANCE I

MODELS	Condemnations			Repair Begins Immediately			Indep. Repair Times			Repair Policy		
	Org.	Inter.	Depot	Org.	Inter.	Depot	Org.	Inter.	Depot	Org.	Inter.	Depot
METRIC	N	N/M	N	Y	N/M	Y	Y	N/M	Y	(S-1,S)	N/M	(S-1,S)
MOD-METRIC	N	N/M	N	Y	N/M	Y	Y	N/M	Y	(S-1,S)	N/M	(S-1,S)
DYNA-METRIC	N	N/M	N	Yw/osim Nw/sim	N/M	Y	Yw/osim Nw/sim	N/M	Y	(S-1,S)	N/M	(S-1,S)
AAM	Y	N/M	Y	Y	N/M	Y	Y	N/M	Y	(S-1,S)	N/M	(S-1,S)
WARS	Y	N/M	Y	Y	N/M	Y	Y	N/M	Y	(S-1,S)	N/M	(S-1,S)
SESAME	Y	Y	Y	Y	Y	Y	Y	Y	Y	(S-1,S)	(S-1,S)	(S-1,S)
ACIM	N	Y	Y	Y	Y	Y	Y	Y	Y	(S-1,S)	(S-1,S)	(S-1,S)
MIME	N/M	N	Y	N/M	Y	Y	N/M	Y	Y	N/M	(S-1,S)	(S-1,S)
CAPLOG	Y	N/M	Y	Y	N/M	Y	Y	N/M	Y	(S-1,S)	N/M	(S-1,S)
AWARES	Y	Y	Y	Y	Y	Y	Y	Y	Y	*	*	*
S4	N/M	N/M	Y	N/M	N/M	Y	N/M	N/M	Y	N/M	N/M	(s,S)
FBM	N/M	N/M	Y	N/M	N/M	Y	N/M	N/M	Y	N/M	N/M	(S-1,S) and (s,S)
5A	N	N	Y	N	N	Y	N	N	Y	N	(s,S)	(S-1,S) and (s,S)
SPECTRUM	N	N	N	N	N	N	N	N	N	(S-1,S)	(S-1,S)	(S-1,S)
METEOR	N/M	N/M	N	N/M	N/M	Y	N/M	N/M	Y	N/M	N/M	(s,S)
TIGER	N/M	N/M	N/M	N/M	N/M	N/M	N/M	N/M	N/M	N/M	N/M	N/M
TSAR	Y	Y	N/M	N	N	N/M	N	N	N/M	(S-1,S)	(S-1,S)	N/M
U.S.Navy	N	N	Y	N	N	N	N	N	N	(S-1,S)	(S-1,S)	(S-1,S)

* No echelon will repair a component until a repair time before it is anticipated that one of three criteria will be violated (see AWARES abstract).

MAINTENANCE II

MODELS	CANNIBALIZATION ORG.	INTER.	DEPOT
METRIC	N	N/M	N
MOD-METRIC	N	N/M	N
DYNA-METRIC	Y	N/M	Y(OPTION)
AAM	N	N/M	N
WARS	Y	N/M	N
SESAME	N	N	N
ACIM	N	N	N
MIME	N/M	N	N
CAPLOG	Y	N/M	N
AWARES	Y	Y	Y
S4	N/M	N/M	N
FBM	N/M	N/M	N
5A	Y	N	N
SPECTRUM	Y	N	N
METEOR	N/M	N/M	N
TIGER	N/M	N/M	N/M
TSAR	Y	Y	N/M
U.S.Navy	Y	Y	Y

SUPPLY

MODELS	RESUPPLY POLICY CONS.	RESUPPLY POLICY INTER.	RESUPPLY POLICY WHOLE	OUTSIDE PROCUREMENT CONSIDERED CONS.	OUTSIDE PROCUREMENT CONSIDERED INTER.	OUTSIDE PROCUREMENT CONSIDERED WHOLE
METRIC	(S-1,S)	N/M	N/M	N	N/M	N
MOD-METRIC	(S-1,S)	N/M	N/M	N	N/M	N
DYNA-METRIC	(S-1,S)	N/M	N/M	N	N/M	N
AAM	(S-1,S)	N/M	(S-1,S)	N	N/M	Y
WARS	(S-1,S)	N/M	(S-1,S)	N	N/M	Y
SESAME	(S-1,S)	(S-1,S)	(S-1,S)	N	N	Y
ACIM	(S-1,S)	(S-1,S)	(S-1,S)	N	N	Y
MIME	(S-1,S)	(S-1,S)	(S-1,S)	N	N	Y
CAPLOG	(S-1,S)	N/M	(S-1,S)	N	N/M	Y
AWARES	*	*	*	N	N	Y
S4	(s,S)	(s,S)	(s,S)	N	N	Y
FBM	N/A	(s,S)	(s,S)	N	N	Y
5A	(s,S)	(s,S)	(s,S)	N	N	Y
SPECTRUM	(s,S)	(s,S)	N/M	N	N	Y
METEOR	(s,S)	(s,S)	(s,S)	N	N	Y
TIGER	N/M	N/M	N/M	N/M	N/M	N/M
TSAR	(S-1,S)	(S-1,S)	N/M	N	N	N/M
U.S.Navy	Consumable (s,S) Repairables (S-1,S)	(s,S)	(s,S)	N	N	Y

* No echelon will requisition a replacement component until an order and ship time before it is anticipated that one of three criteria will be violated (see AWARES abstract).

B. INFERENCES DRAWN FROM THE MATRIX. This section is divided into three parts: Unique Features of Some Models, Similar Features Across All (or Almost All) Models and Pluses and Minuses of the Models from the Navy's View.

1. Unique Features of Some Models. This section features characteristics of the models which only a few of the models possess. TABLE III displays 12 of these characteristics along with the models which have these characteristics. As can be seen in TABLE III only the SESAME, ACIM and AWARES models can have (theoretically) an unlimited number of echelons while only the ACIM, TIGER and AWARES models can have (theoretically) an unlimited number of indenture levels. In general, simulation models can handle a changing level of operations. However, the only analytic models which can handle a changing level of operations are the DYNA-METRIC, WARS, CAPLOG and AWARES models. The CAPLOG, AWARES and TSAR models are the only models which do not use a probability distribution in the model. The only models which allow any lateral resupply are the FBM, S4, METEOR and TSAR models and the TSAR model is the only model to consider whether a repair would occur at a repair facility based on the backlog at the facility. The TIGER, MIME and METEOR models were the only models which dealt with redundancy while only the FBM, TSAR, WARS and SPECTRUM models attempt to handle partial degradation of a system. Once a decision to repair had been made every model except the DYNA-METRIC, 5A, TSAR and SPECTRUM models assume that the repair begins immediately and only the 5A, FBM, S4 and AWARES models allow a repair policy which will batch repairs. The 5A, S4, SPECTRUM, FBM, METEOR and AWARES models are the only models that do not assume a "use one, order one" resupply policy. Procurement outside of the supply system is not handled by the METRIC, MOD-METRIC, DYNA-METRIC, TIGER or TSAR models.

TABLE III

UNIQUE MODEL FEATURES

	METRIC	MOD-METRIC	DYNA-METRIC	AAM	WARS	SESAME	ACIM	MIME	CAPLOG	AWARES	S4	FBM	5A	SPECTRUM	METEOR	TIGER	TSAR
Variable Number of Echelons						X	X			X							
Variable Number of Indenture Levels							X			X						X	
Analytic Models Which Allow a Change in Level of Operations Over Time			X		X				X	X	N/A	N/A	N/A	N/A	N/A	N/A	N/A
No Distribution									X	X							X
Lateral Resupply Allowed											X	X			X		X
Where Repair Occurs Depends on Backlog																	X
Redundancy Considered								X							X	X	
Partial Degradation Considered					X							X		X			X
Repair Does Not Begin Immediately			X										X	X			X
Allows Repair Policy Other Than (S-1,S)										X	X	X	X				
Allows Resupply Policy Other Than (S-1,S)										X	X	X	X	X	X		
No Outside Procurement Allowed	X	X	X													X	X

2. Similar Features Across All (or Almost All) Models. There are five characteristics which all (or almost all) of the models have. All of the models handle repairable items and all but three of the models (5A, S4 and TSAR) are weapon system oriented. The pipeline distribution is the basis for all of the analytic models except for the CAPLOG and AWARES models while the demand distibution is the basis for all of the simulation models except for the TSAR model. All of the models which consider the repair process used the complexity of repair in determining where the repair is accomplished.

3. Pluses and Minuses of the Models from the Navy's View. Each of the models analyzed in this study has a unique combination of structure, assumptions, objectives and procedures. Some of these characteristics, from the Navy's point of view, are features which make these models attractive or unattractive. An attractive feature of almost all of the models is that they are weapon system oriented. However, except for the AWARES, CAPLOG, AAM, MIME, TSAR and SPECTRUM models, only a single weapon system can be handled at a time. Another attractive feature of the ACIM, METEOR, 5A, S4, FBM, MIME and SPECTRUM models is that, since they were developed for Navy applications, they closely model the Navy's supply operations. However, because the FBM model was developed specifically for Poseidon class submarines, it's application is limited and the model will eventually become obsolete as the TRIDENT weapons system replaces the Poseidon weapons system.

Two unattractive features of the Air Force models (METRIC, MOD-METRIC, DYNA-METRIC, AAM, WARS and TSAR) are that they are base/depot models (which do not represent the Navy's supply system) and they are strictly aircraft oriented. An unattractive feature of the METRIC, MOD-METRIC, DYNA-METRIC, TIGER and TSAR models is that procurement is not considered. The TIGER model represents the logistic system in a cursory manner which makes it unattractive for supply system analysis while the SPECTRUM, WARS and TSAR models appear cumbersome in terms of execution.

IV. Summary

The Navy currently uses inventory models which determine the optimal inventory policy for each activity or echelon of supply independently of any of the other supply activities. Multi-echelon inventory models have been developed to model entire supply systems rather than the individual activities or echelons which make up the supply network. In addition, the Navy uses supply effectiveness measures which are requisition oriented rather than readiness oriented. Congress is now requiring the military services to project the effect of appropriations requested on material readiness requirements. Therefore, most multi-echelon models have been developed to feature both a readiness performance measure and the multi-echelon supply system modeling.

A plethora of multi-echelon models have been proposed for use or are currently being used by the military services for at least one of three purposes: (1) to tie budget dollars to readiness, (2) to determine the inventory levels at each echelon of supply given a readiness objective, or (3) to predict readiness given the inventory levels at each echelon of supply. This study examined and contrasted the characteristics of the multi-echelon models used or proposed for use in the military services, based on each model's available documentation, in order to choose models which may fit the Navy's needs. TABLE IV lists the models examined in this study and contains a summary/

comment on each model. An asterisk indicates that FMSO recommends a more in-depth study of that model which would exercise the model with test data.

The ACIM model was developed for the Navy by CACI for requirements determination. Based on the information gathered in this study, there is no reason to prefer any other requirements determination model over ACIM. However, none of the models in this study were exercised with data.

A more in depth analysis which concentrated on only a few of the requirements determination models and tested the models with data would be a valuable analysis. The SESAME, AAM and MIME models should be analyzed in more depth along with the ACIM Model. The SESAME model is used by the Army in provisioning. The SESAME model's method of determining levels for lower indenture parts based on economic considerations separately from the other parts should be further analyzed. The AAM model's method of handling the effect of common components across multiple weapon systems should be investigated. The MIME model was designed based on the Navy supply system and its handling of redundancy should be further investigated. The WARS model appears to be primarily Air Force oriented and cumbersome, while the METRIC models do not consider procurement.

For evaluation of inventory levels, the 5A and METEOR models, which were designed based on the Navy's supply system, represent that system better than any of the other evaluation models. The S4 model is part of the 5A model while the TIGER model is part of the METEOR model. Even though the SPECTRUM and FBM models are based on the Navy supply system, the SPECTRUM model is cumbersome while the FBM model is narrow in its application. The TSAR model appears to be primarily Air Force oriented and to be cumbersome.

TABLE IV

SUMMARY OF MULTI-ECHELON MODELS

OPTIMIZATION	SUMMARY COMMENT
ACIM*	Approved for Navy use
AAM*	Used by Air Force for POM & budget
SESAME*	Army provisioning model
MIME*	Based on Navy supply system
WARS	Too cumbersome
DYNA-METRIC	Extension of MOD-METRIC (dynamic aspect)
MOD-METRIC	Extension of METRIC (indenture levels)
METRIC	First implemented multi-echelon model

EVALUATION	
5A*	Models Navy's supply system; synthesizer
METEOR*	Analyzes multi-echelon models in terms of the Navy's supply system
S4	Superseded by 5A
TIGER	Part of METEOR
SPECTRUM	Too cumbersome
FBM	Too narrow
TSAR	Too Air Force oriented; too cumbersome
AWARES*	"Quick and dirty" model based on averages
CAPLOG*	"Quick and dirty" model based on averages

* indicates a model recommended by FMSO for further study

The AWARES and CAPLOG models and the synthesizer module of the 5A model should be investigated in more depth to determine if they can be used to give "quick and dirty" answers to tying budget dollars to readiness questions. The AWARES and CAPLOG models were designed to assess the effects of varying resource levels on the peacetime material readiness and wartime sustainability of U. S. aviation and the U. S. Navy, respectively. The synthesizer module of the 5A model will project Requisition Response Time on a quick response basis.

The Navy is currently investigating techniques for using item essentiality in levels determination for all supply echelons. It was beyond the scope of this study to investigate how each multi-echelon inventory model relates item essentiality and levels determination. However, this relationship will be investigated in the more in-depth analyses.

V. RECOMMENDATIONS

FMSO recommends that the CAPLOG, AWARES and 5A synthesizer models be further analyzed for use in giving "quick and dirty" answers to tying dollars to readiness questions. FMSO also recommends that the ACIM, AAM, MIME and SESAME models be further analyzed for use in requirements determination and that the METEOR and 5A models be further analyzed for use in evaluating inventory levels.

FMSO recommends that the additional studies be performed in the following sequence:

- Budget dollars to readiness models
- Evaluating inventory levels models
- Requirements determination models

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APPENDIX B: DETAILED MATRIX

APPENDIX B contains a matrix of information not included in TABLE II of the main report. The matrix in APPENDIX B contains information on program size, run time and input data.

Explanation of the matrix column titles follows:

1. General.

Program Size (K): The Program Size (K) column specifies the size of the computer program in terms of K (kilobyte).

Run Information: The three columns under Run Information give some indication as to how much computer time it takes to run the model. The "Time" column indicates the time. The "Items" column indicates how many items were processed in the run and the "Machine" column indicates on what type of computer the run was made. Ideally, the information contained in the matrix for a model would complete the sentence: The METRIC model took 5 min for 1000 items on the IBM 3081 machine. However, information in this format could not be obtained. Therefore, the best information we could get is in the matrix. Columns left blank indicate that no information could be obtained.

2. Input Data - Sections marked Input I and II contain information about the input data needed to run each model. Not all of the data elements needed to run each model are included in these two sections. Rather these two sections contain data elements which give an indication of the type of data needed to run the model. Each section contains a key which defines the codes used to specify the type of data required.

Var to Mean Ratio - This column indicates whether the model requires a variance to mean ratio for the probability distribution(s) used in the model.

End Item MTBF - This column indicates whether the model requires an end item mean time between failure as an input.

End Item MTTR - This column indicates whether the model requires an end item mean time to repair as an input.

Procurement L.T. - This column indicates whether the model requires procurement leadtime as an input.

Unit Cost - This column indicates whether the model requires an item's unit cost as an input.

Wholesale FILL Rate - This column indicates whether the model requires the probability of filling a requisition at the wholesale level of supply as an input.

Essentiality - This column indicates whether the model requires an essentiality value as an input.

Demand Input - This column indicates whether demand information is input into the model as a rate (for example, average quarterly demand) or as actual demand transactions.

Depot TAT - This column indicates whether the model requires repair turn around time at the depot level of maintenance as an input.

Interm. TAT - This column indicates whether the model requires repair turn around time at the intermediate level of maintenance as an input.

Organ. TAT - This column indicates whether the model requires repair turn around time at the organizational level of maintenance as an input.

OST - This column indicates whether the model requires order and ship time as an input.

Where Repair Occurs Rate - This column indicates whether the model requires a where repair occurs rate. A where repair occurs rate is used by the model to determine where a carcass will be repaired.

Condemnation Rate - This column indicates whether the model requires a condemnation rate as an input. A condemnation rate is used in the model to determine if a carcass can be economically repaired.

Carcasses Not Returned Rate - This column indicates whether the model requires a carcasses not returned rate. A carcasses not returned rate is used by the model to determine if a carcass is lost in transit to the repair facility.

GENERAL

MODELS	PROGRAM SIZE(K)	RUN INFORMATION TIME	 ITEMS	 MACHINE
METRIC MOD-METRIC	40K	4 hrs. for a Weapon Sys		
DYNA-METRIC	300K (moderate size version)	4 sec (2 squadron; 1 depot; 30 days)	50	IBM 3033
AAM	40K	1 min for a (CPU) 1/2 hr. (CPU)	Weapon System 40 aircraft types	Honeywell DSP-8 Mini Comp.
WARS				IBM or IBM compatable
SESAME		5 MIN	500	
ACIM	3 pgms: 100K pre 350K main 150K post	9 min	675 (4 equip- 1 echelon)	Bur. 6750
MIME				
CAPLOG				Honeywell Ramus II
AWARES				
S4				
FBM	265K			IBM360/65
5A . Wholesale . Stock Point . IMAGE . LASER	 225K 175K 70K 80K	 6 min 3 min	 7 aircraft types 317 WRA 704 SRA 2280 parts	 IBM 360 IBM 360 CDC 6600 CDC 6600

GENERAL (CONT'D)

MODELS	PROGRAM SIZE(K)	RUN INFORMATION TIME	ITEMS	MACHINES
SPECTRUM . PRISM .. OPTICS	370K	25 min CPU	for 120 cruise	IBM 360/158
.. IMAGE	350K	30 min CPU	for 176 day cruise	IBM 360/158
.. PEER	360K			
.. LASER	400K	20 min CPU	for 122 day cruise	IBM 360/158
. RETINA		140 sec	for 300 NIINs	CDC 6600 & CDC CYBER175
METEOR		4-8 secs CPU	1000 missions of duration 5000 hrs.	IBM 3033
TIGER	51K	300 secs 38 secs	200 types of equip. 500 equips. 5 phase types	CYBER 176 CRAY
TSAR	520K	10 min CPU	216 aircraft for 10,000 sorties	IBM 370

S = SYSTEM
I = ITEM
C = ITEM AND BASE
Ec = ECHELON

E = END ITEM/WEAPONS SYSTEM
N/A = NOT APPLICABLE
N = NO
R = REQUIRED

INPUT

MODELS	VAR TO MEAN RATIO	END ITEM MTBF	END ITEM MTTR	PROCURE-MENT L.T.	UNIT COST	WHOLE-SALE FILL RATE	ESSENTIALITY	DEMAND INPUT
METRIC	S	N/A	N/A	N/A	I	N/A	C	Rate
MOD-METRIC	N/A	N/A	N/A	N/A	I	N/A	C	Rate
DYNA-METRIC	S	N	N	N	I	N	I	Rate
AAM	S	N	N	I	I	N	N	Rate
WARS	R	N/A	N/A	S	I	N	I	Rate
SESAME	N/A	E	E	S	I	S	I	Rate
ACIM	N	E	E	I	I	N	I	Rate
MIME	N/A	I	I	I	I	N	N	Rate
CAPLOG	N/A	N/A	N/A	I	I	N	I	Rate
AWARES	N/A	N/A	N/A	R	I	R	N	Rate
S4	N/A	N/A	N/A	I(Dist)	I	N/A	N	Dmd. Transactions
FBM	N	N/A	N/A	I(Dist)	I	N	I	Dmd. Transactions
5A	N/A	N/A	N/A	I(Dist)	I	N/A	I	Rate/ Dmd. Transactions
SPECTRUM	N/A	N/A	N/A	N	I	N	N	Rate
METEOR	N/A	I	I	I(Dist)	I	N/A	N/A	Rate
TIGER	N/A	I/E	I/E	N/A	N/A	N/A	N/A	Rate
TSAR	N/A	N/A	N/A	N/A	I	N/A	I	Rate

S = SYSTEM
I = ITEM
C = ITEM AND BASE
Ec = ECHELON

E = END ITEM/WEAPONS SYSTEM
N/A = NOT APPLICABLE
N = NO
R = REQUIRED

INPUT

MODELS	DEPOT TAT	INTERM. TAT	ORGAN. TAT	OST	WHERE REPAIR OCCURS RATES	CONDEM-NATION RATE	CARCASSES NOT RETURNED RATE
METRIC	I	N/A	C	C	C	N/A	N/A
MOD-METRIC	I	N/A	C	C	C	N/A	N/A
DYNA-METRIC	I	N/A	I	C	C	I	N/A
AAM	I	N/A	I	I	C	Ec	N/A
WARS	I	N/A	I	I	I	I(Ec)	N/A
SESAME	I	I	I	E	I	I	E
ACIM	I	C	C	C	I	I	N/A
MIME	I	I	N/A	Ec	I	I	N/A
CAPLOG	I	N/A	I	I	I	Ec	N/A
AWARES	I	I	I	I	I	I	I
S4	I	N/A	N/A	I(Dist)	N/A	I	I
FBM	I	N/A	N/A	I(Dist)	N/A	I	I
5A	I(Dist)	I	N/A	I(Dist)	I	N/A	I
SPECTRUM	N	N	N	R	I	N/A	N/A
METEOR	I(Dist)	N/A	N/A	S	N/A	N/A	S
TIGER	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TSAR	N/A	R	R	R	C	R	R

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13. ABSTRACT

The Navy currently uses inventory models which determine the optimal inventory policy for each activity or echelon of supply independently of the other supply activities. In addition, the Navy uses supply effectiveness measures which are requisition oriented rather than readiness oriented. Many inventory models, known as multi-echelon models, have been developed which feature both a readiness performance measure and multi-echelon supply modeling. The multi-echelon models which have been proposed for use or are currently being used by the military services have at least one of three purposes: (1) to tie budget dollars to readiness, (2) to determine the inventory levels required at each echelon of supply given a readiness objective, or (3) to predict readiness given the inventory levels at each echelon of supply. Therefore, the model which is "best" for the Navy will depend on the Navy's intended use of the model. This study examines and contrasts the characteristics of the multi-echelon models currently used or proposed for use in the military services, in order to choose models which may fit the Navy's needs.

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